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ECL 268

HUMAN FACTORS IN THE DESIGN OF MACHINERY CONTROLS

A sanitation worker, attempting to free a wooden pallet which had jammed his collection truck's compactor, had several fingers of one hand crushed. The worker sued the truck manufacturer. The case provides an opportunity to consider ways of maximizing user safety.

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The Circumstances

In August 1979, a santitation man in Edison, New Jersey attempted to free the compaction mechanism of one of his department's refuse collection trucks. Part of a wooden pallet had jammed this mechanism preventing it from sweeping a quantity of refuse from its hopper, and loading it into the truck's interior.

In normal operation, when the hopper is sufficiently filled with refuse, or a portion of the collection route is completed, the operator signals the truck driver to engage the power take-off mechanism. The operator first initiates the packing portion of the loading cycle by exerting a downward force on the outer control lever. He then switches over to the inner lever to sweep the compacted refuse up into the body of the truck, (see Figures 1 and 2).

In this incident, the operator continued depressing the outer lever. This allowed the packer-sweeper blade to bypass its built-in interrupted cycle stop point. This point is used for halting the cycle whenever jams occur. But in this case, the presence of a piece of wood from a pallet caused the blade to stop before it was able to complete the packing cycle.

The operator then pushed the outer control lever upwards with his right hand. This reversed the direction in which the packer-sweeper blade was moving, causing it to rise by approximately one foot. He then used his left hand to try to push the wooden pallet remnant deeper into the hopper. Next he again reversed the operating lever to move the blade downward. But this series of actions was of no help in unjamming the wooden piece. The sequence was repeated four or five times as the operator jockeyed the outer control lever. During his last attempt, while his left hand was still on the piece of wood, the blade was finally freed. It suddenly jerked forward and descended severely crushing his left hand before the blade could be stopped.

The Equipment Involved

The most widely used type of solid waste collection truck is the enclosed compactor. Its major advantage is that it is able to compact the collected refuse very tightly so that fewer daily trips to the incinerator or landfill are required. This feature greatly increases operational efficiency.

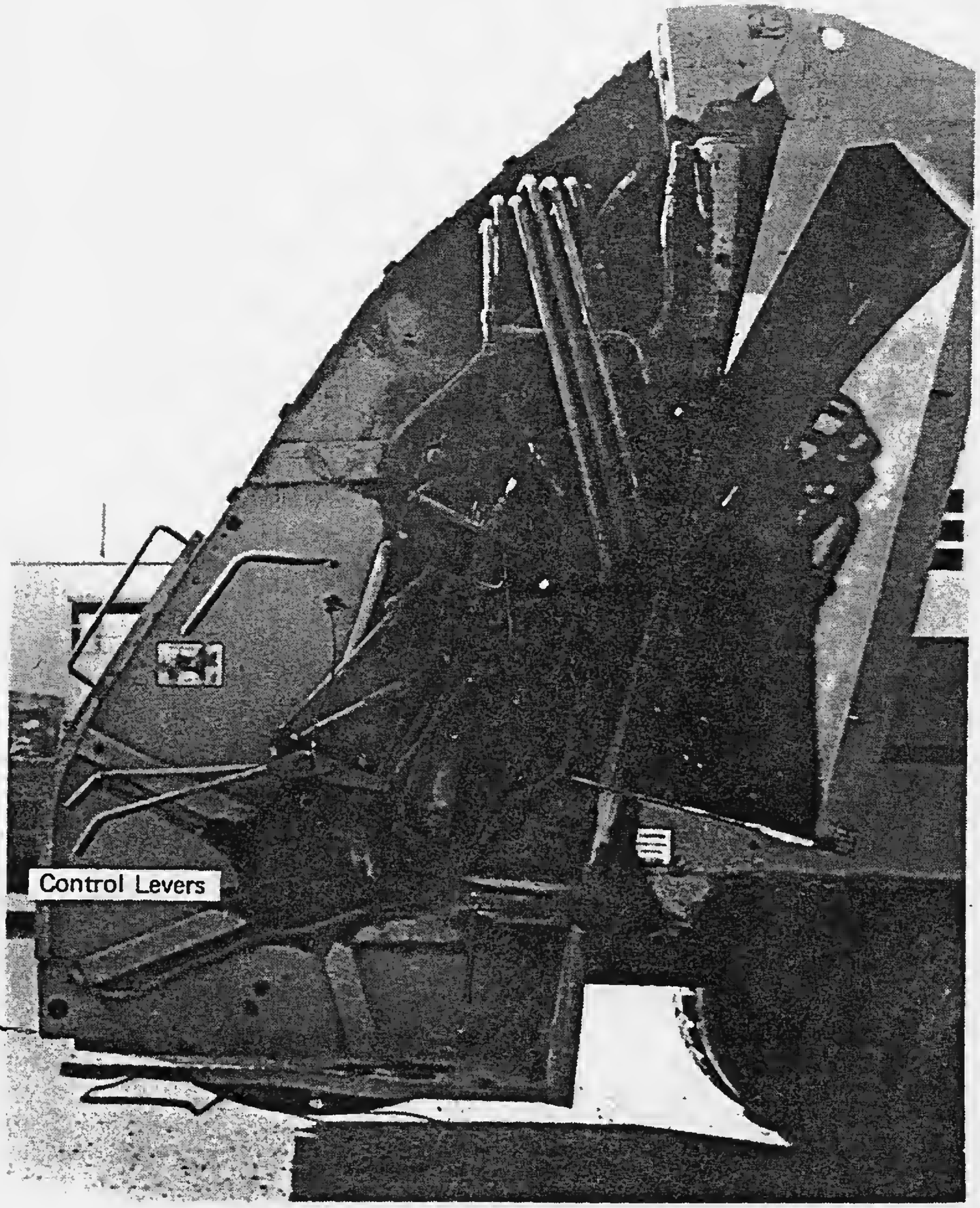


Figure 1

Original Refuse Collection Truck

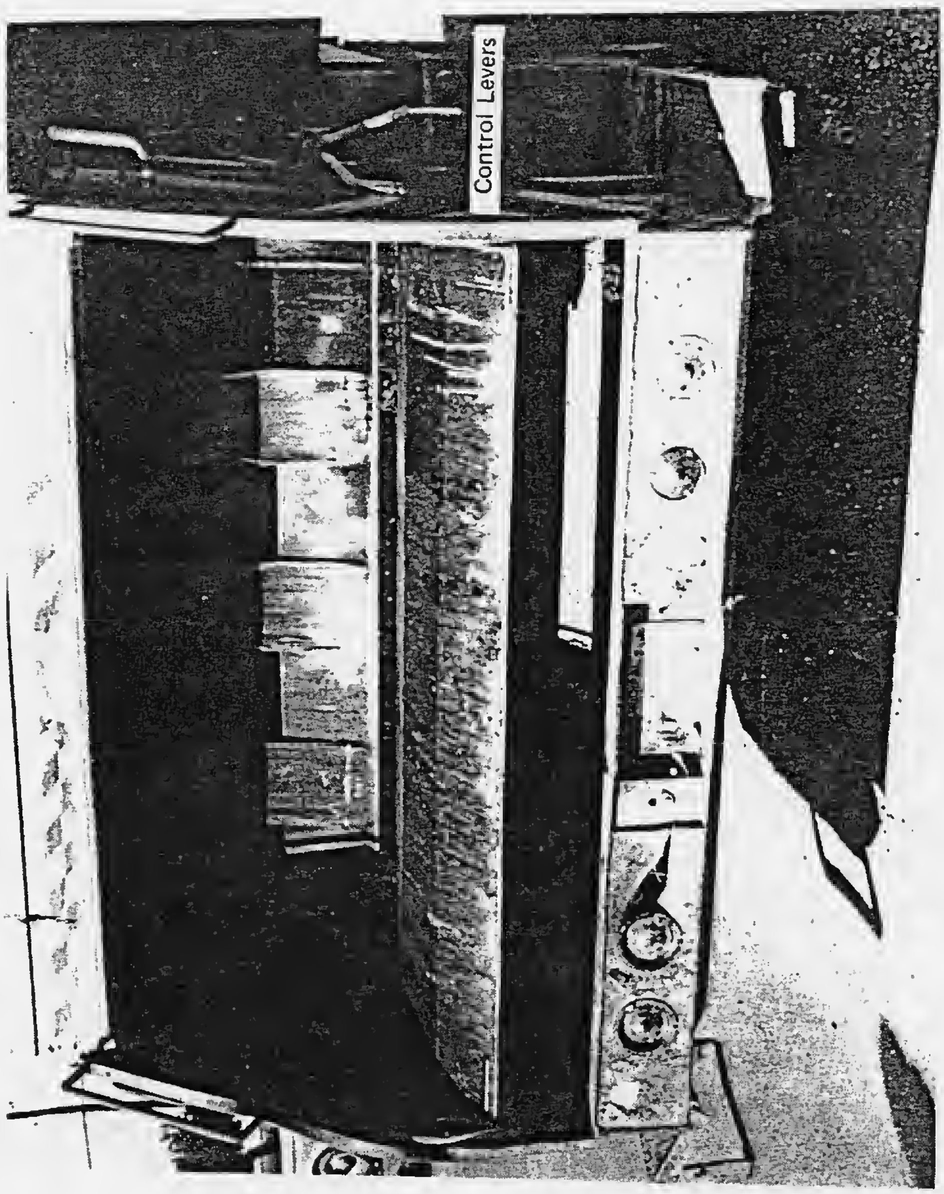


Figure 2

Hopper of Original Refuse Collection Truck

General functional requirements for the controls of such compactor trucks include the following points. They should be: easy to operate, rugged, fool proof, and convenient. Their usage must not add significantly to the operator's workload by taking up any more of his time than is absolutely necessary.

These trucks are called batch type collection vehicles. Naturally, the fewer daily trips the truck must make to the dump, the more efficient the colloction operation. Therefore the refuse is first compressed in the hopper and then swept by the blade into the body of the truck. This is why the formal name for this component is the "packer-sweeper blade". The truck only leaves for the dump when its interior is fully packed with compacted trash. At this point it is usually hauling several tons of refuse.

Such trucks generally feature a double cycle packer mechanism which is powered from the truck's engine. It should only be activated after the gear shift has been placed in neutral. The hopper and blade are so designed to provide an upward packing action. Refuse is first dumped into a hopper which is located as close to the ground as possible (7). In most cases, this is approximately 30 inches above the pavement. The blade follows a set of guide rails to first drop down and sweep the hopper. It then begins a forward and upward packing motion while flush against the frame of the truck.

The blade is often equipped with two stop operating controls which permit it to stop automatically about halfway through its movement cycle. The remaining control, must then be actuated to continue and complete the entire cycle. One or more stop buttons should be provided in convenient locations to halt operations as rapidly as possible. But the use of these special devices should be restricted to emergencies only.

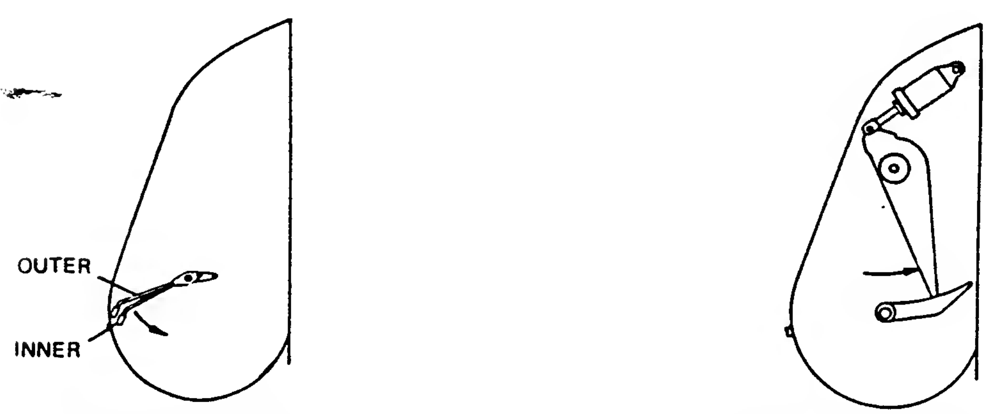
Three drawings taken from the manufacturer's operational and maintenance manual for this truck are shown in Figure 3. They depict how the control levers function in the operation of the packer-sweeper blades. The compaction mechanism found in the truck involved in this accident features an interrupted stroke which stops the packer-sweeper blade approximately 12 inches above the lower sill of the hopper. Such a built-in clearance is intended to serve as a safety feature. The interrupted cycle for compactor controls was not required by the applicable ANSI standard which was in effect at the time this truck was manufactured. It has since become a standard feature. Despite the improved safety it provides equipment operators, it will be seen that

POSITION OF CONTROL HANDLES　　　POSITION OF PACKING MECHANISM

Starting Position

POSITION OF CONTROL HANDLES　　　POSITION OF PACKING MECHANISM

Initiating the Packer-Sweeper Cycle



POSITION OF CONTROL HANDLES　　　POSITION OF PACKING MECHANISM

Completing the Packer-Sweeper Cycle

Figure 3
Sequence of Control Operations

this feature can be easily overridden. From the intermediate point, the blade then drifts down to its resting position. The entire cycle takes between 15 and 20 seconds to complete. But this time period could be reduced to approximately six seconds if the operator chooses to bypass the interrupted cycle stop point by continuously depressing the outer control lever. This so-called rapid cycle can be divided into three sequential segments:

1. from the cam starting point to the stop point, 3 seconds
2. from here to when the blade passes the hopper sill, 1 second
3. from here to the blade's final resting position, 2 seconds

The control mechanism used to operate the packer-sweeper blade consists of two cylindrical rods which are located near the right rear corner of the truck. The outer lever activates the packing portion of the cycle, while the inner lever activates the sweeping portion. Each lever is 21 inches long and has a similar rubber handle which is four inches long and one and one-half inches in diameter. These handles are situated approximately four feet off the ground and generally orient the levers parallel to the side of the truck and its axis of loading. The inner lever clears the side of the truck by approximately three inches, and both levers terminate five inches from the rear of the truck.

A field inspection revealed that although roughly parallel to each other, the levers are six inches apart at their handles and converge to one and a half inches apart before meeting at a common joint. Their operational movements are quite similar - relatively small vertical rotations in both the clockwise (upward) and counter-clockwise (downward) directions which produce ~~much~~ larger arcs of rotation in the packer-sweeper blade. The inner lever appears to have no measurable deadspace, while the outer lever contains deadspace of approximately 10 to 15 degrees of arc. In this zone, handle movements do not result in any corresponding output by the compactor mechanism.

The recognized standard for refuse collecting and compacting equipment is ANSI Z 245.1 (Ref. 1). The most recent edition, (1984) is an update of earlier versions one of which, (1975) was in effect when the truck involved in this accident was manufactured. Section 7.1.4 of the current standard covers controls for mobile equipment. This section reads as follows:

1. Controls shall be conspicuously labeled as to their function.

2. Sustained manual pressure controls shall be used for raising the body or tailgate or moving the hoisting or lifting mechanisms or the ejector panel.

3. Electrically controlled components operated by push buttons shall have start buttons recessed or located to prevent unintentional activation. Stop buttons shall be red, distinguishable from all other controls by size and color, and not be recessed.

4. Controls for raising or opening the tailgate, raising the body, or unloading the compacted refuse shall be located away from the rear of the equipment.

5. For emergencies, a means of stopping a packing cycle at any point and a means of reversing the packing mechanism away from any pinch point shall be provided.

This brief discussion, while incorporating sound safety principles, still leaves designers a great deal of freedom in arranging and specifying the length, position, orientation and method of operation of their compactor controls.

Questions - Part A

1. Why should the height of the hopper be as close to the ground as possible?

2. Why should the use of blade stop buttons be restricted to emergency situations only?

3. Can you think of any ways by which the safety features of the controls can be bypassed? Does this represent a weakness in their design?

4. What type of control operation (sustained or momentary) is preferred for the compactor of a refuse collection truck?

a. Explain your choice from both a general and man-machine system perspective.

b. How does your selection effect operator safety?

Legal Proceedings

This case never did come before a judge and jury. It was settled long before that stage by agreement between the attorney for the injured party and the manufacturer's insurance carrier. Shortly after the date of the accident (1979), the manufacturer filed for bankrupcy. It is alleged that one of the reasons for the company's financial plight was the many product liability suits filed against it by sanitation men who were injured while using its refuse collection trucks. But this contention is difficult to confirm. In any event, the insurance company was anxious to settle all pending claims and close the books on its former client. It therefore made what the other side considered to be a reasonable offer, and the case was settled.

The sanitation man's injuries turned out to be not as serious as first feared. He recovered most of the function in his crushed hand through a program of surgery combined with rigorous physical therapy.

Although the full scope of adversary proceedings was never developed here, from experience in other similar cases it is relatively easy to predict what would have happened had this suit not been settled so quickly. We can put ourselves in the position of the engineer retained by the defense and develop the points which he or she would likely have emphasized.

1. Common Sense - Nobody with any brains should place his hand or any other other part of his body into the hopper of a refuse collection truck while its packer-sweeper blade is descending. Even if you saw the crown jewels lying in the hopper, you should still use the controls to first halt the blade's downward motion before attempting to retrieve them. This hazard is so obvious that we cannot fault a design which fails to take into account the possibility that it may be ignored.

2. A Lack of Training - This accident took place less than two months after the injured worker started on his job. An investigation revealed that the local sanitation department did not have either a formal or rigorous training program for its new employees. After a brief period of familiarization with the equipment at the municipal garage, the new worker was allowed to begin going out on regular collection routes. Shortly thereafter, he was allowed to begin operating the controls of his refuse collection truck. Precious little

time within his training program was devoted to either safety, or to the recognition of potential hazards. The general approach followed was to learn by watching and doing.

3. <u>Standards</u> - There were no standards issued either by government agencies, ANSI, or any other group which specifically cover the design of controls for refuse collection trucks at the time when the vehicle in question was manufactured. The applicable ANSI standard, Z 245.1-1975, was quite general in its treatment of this subject. The left designers free to choose between many options. Also, the inclusion of such general types of safety devices as barriers, gates, or interlocks was not mandated by that standard. Extensive field experience has shown that many of these devices quickly become disabled because of the truck's difficult operating environment. Their presence may then even become counter-productive; that is, they may constitute an adiitional hazard rather than a safety feature.

<u>Questions - Part B</u>

1. The three defense contentions discussed above all have some validity. How would you refute them, one by one? Treat each of the following areas,

a. Discuss contributory negligence and the change in attitude of the law towards this concept.

b. Who should bear the responsibility for the operator's inadequate training, and how does this point affect the suit?

c. Discuss the role played by worker's compensation in this case.

d. What is meant by the phrase "deep pockets approach", and how does it apply here?

2. Is it possible to redesign the controls for the packer-sweeper blade to minimize opportunities for this type of accident to be repeated in the future?

3. What are the other major occupational hazards faced by sanitation workers during refuse collection? Which of these hazards can be reduced by point of operation guards and which cannot?

4. What other steps can you suggest to upgrade the safety of this specific job situation?

5. Can the manufacturer fulfill his obligations with

regard to worker safety by posting warnings of the most significant hazards directly on the product itself? Discuss the pros and cons of this approach.

Instructor's Notes

After the students have been given an opportunity to grapple with this problem, a class discussion emphasizing the following subject matter should be conducted. The class should be introduced to the direct solution - point of operation guarding, as well as other approaches such as special types of control systems. All of the other conceivable solutions developed by the students should also be evaluated. The objective here should be for the class to critique each approach by comparing its respective advantages and limitations. The effects of each proposal on both system efficiency and operator safety should be analyzed.

Within these evaluations, human factors considerations can be developed. Any specific points relating to this case can then be generalized for application to all appropriate man-machine systems. As a last step, the role of warnings as an essential back-up to sound design should be noted.

By following such an approach, the instructor should be able to sensitize students to the roles played by people in such interactive systems. Considering both their capabilities and limitations is an essential part of the designer's job, but one which is often treated inadequately if at all. Filling this void is the best way to prevent the development of future unsafe designs which expose systems' operators to excessive or unnecessary risk.

The Direct Solution

In order to transfer refuse from the hopper to the truck's interior, the blade must fully sweep the hopper loading zone very closely. This requirement creates several pinch points which are difficult to avoid. The extent of these pinch point hazards is shown in Figure 4.

The simplest and most direct way to eliminate the hazards associated with such pinch points is to install a conventional point of operation guard across the entire width of the hopper. These movable barrier guards are generally known as safety gates. One such gate is shown in its up and down position in Figures 5 and 6 respectively.

The National Safety Council in its Data Sheet 618, "Refuse Collection in Municipalities" states that:

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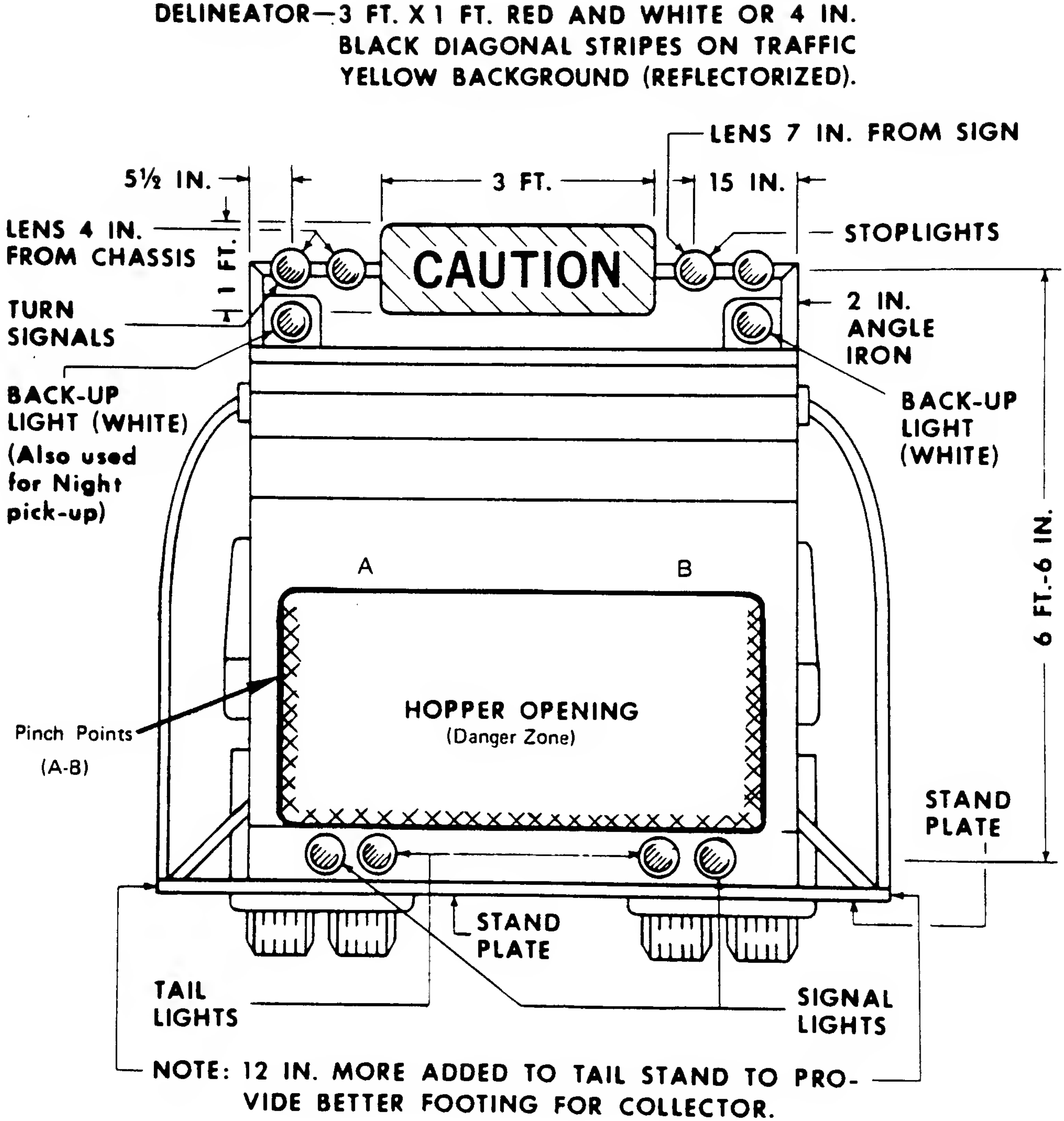

Figure 4

Refuse Collection Truck

(Rear View)

Figure 5

Safety Gate in Up Position

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Figure 6

Safety Gate in Down Position

From Industrial Data Sheet No. 618, "Refuse Collection in Municipalities," copyright by National Safety Council, Chicago, Ill. 60611. Used with permission.

". . . it is obvious that a safety gate can provide the mechanical safeguards which will protect employees from direct contact with moving parts. A specially designed safety gate has been developed for the packer-loader type mechanism. With a simple control, the safety gate is released to an "up" position which keeps the worker away from the blade. This part of the operation is "spring loaded" and calls for a minimum effort on the part of the operator. The blade descends only when the gate is up and the hopper is loaded by a downward movement of a control lever. Safety gates have been successfully installed on some packer type units, and it is a relatively simple device to operate. It consists of a gate 1`-4" by 6`-11" and is installed over the loading area or platform. The gate is made of an angle iron frame covered with expanded metal. The gate is lightweight and affords a view of the packing blade while it is in motion."(10)

The guard is also designed to function as an interlock, since the compaction mechanism cannot be activated until the gate is fully engaged in its up position. This sequencing effectively prevents an operator from inserting his hands or any other part of his body into the hopper loading zone while the blade is in motion. It completely eliminates the opportunity for any dangerous manuevers.

This feature also reduces the exposure workers face from hazards arising from other sources. These include the many dangerous items which are routinely discarded with other trash. For example, charged aerosol containers, bottles of acids, caustics or other dangerous materials, etc. can all cause serious injuries if handled incorrectly. Sanitation men should be trained to visually inspect the refuse and segregate suspicious items before initiating compaction.

Other attendant job hazards remain however even when point of operation guards are included on the collection truck. Back strains, sprains, and dislocations are extremely common due to the heavy lifting involved. Cuts, lacerations and puncture wounds are also regular occurrences because of the need to handle sharp objects, or from the sharp edges on the trash containers themselves (8).

At this point, however, an inexperienced observer might conclude that the problem of protecting santitation men can generally be solved by simply requiring all collection trucks to include a point of operation guard.

Right?

Unfortunately, wrong. As we will soon see, the real world is much more complex.

Safety gates are usually optional features which are only supplied at customer request with many models of refuse collection trucks. Sad to say that they are not ordered by a majority of municipalities and other collection agencies (9). There are essentially two reasons for this:

1. Such guards are presently not required either by law (as prescribed by various governmental regulations) or by accepted industry standards.

2. They tend to lengthen the time required for each collection cycle by a significant amount. This increase directly reduces the functional efficiency of the collection truck - a factor which some collection agencies emphasize in their purchasing decision.

The initial cost added by a barrier guard is not excessive, less than five percent of the purchase price of a new refuse collection truck. They are clearly feasible for field use since no new or sophisticated technology is involved. In fact, several manufacturers have designed and marketed such devices. But because when installed, collection speed is slowed down, there is a temptation for departments or operators to try to remove or defeat them. This may create additional problems or exacerbate existing hazards.

Other Possible Solutions

In general, the ideal way to prevent accidents is to eliminate the hazards responsible for them. We already know that the primary hazards associated with the compactor mechanism on the refuse collection truck are the pinch points created each time the packer-sweeper blade is activated. A minimum amount of clearance is provided between the blade and both of the sides and lower sill of the truck's hopper. The best way to protect operators from exposure to these pinch points is through the use of a point of operation guard, or safety gate. But if this approach is not followed, then other secondary measures should be adopted. Although not as direct, these can be equally effective.

At the outset, designers should keep in mind that although perfectly safe designs or products should always be the ideal to aim for, this goal may not be achieved in all respects. A refuse collection truck is a

potentially dangerous piece of equipment. If improperly handled, its compaction mechanism can kill or seriously injure an operator in a matter of seconds. It comes in contact with many items which are extremely dangerous in themselves. Also, there is a need for operators to work very close to the danger zone with its pinch points. But despite all these potential problems, the relatively high accident rate associated with users of these trucks can be significantly reduced by treating the problem from the perspective of a man-machine system (2, 3, 4).

One key aspect of this approach concerns the contol lever arrangement. To properly evaluate the design of these levers we should consider both the requirements of the job as well as operator safety. The objective here is to come up with a practical arrangement which allows the truck to perform its collection job efficiently while providing a maximum amount of operator safety.

There are two general categories to describe the operation of these controls, - sustained and momentary. With sustained controls, the application of force must be continuous in order for the packer-sweeper blade to move. With momentary controls, once the cycle is completed, the blade continues to move until that portion of the cycle is completed.

Here are three possible approaches to this problem, along with a brief analysis of their respective pros and cons.

1. <u>Two handed controls</u>. One approach which will definitely improve operator safety involves the use of two handed, rather than one handed control levers. The operator can no longer insert his hand into the hopper as the blade descends. This approach has not really been implemented because of the practical problems which it presents. An awkward work stance would probably be required, increasing the chances that the controls would be circumvented, and its safety features defeated. Designers cannot ignore such human factors problems in implementing their ideas.

2. <u>A dead man`s control</u>. The investigation of another accident case revealed that the manufacturer of this truck once offered a dead man's control as an option on certain models. This control requires that the operating lever must be positively held down during the interval from where the blade passes from the interrupted cycle stop point to the lower sill of the hopper. If for any reason the operator stops pushing the control, the packer-sweeper blade also stops moving. The safety advantage of such a feature is obvious, but it too has

never been standardized. The reason for this may lie with the operator's general dislike of any arrangement which cannot be automatically preset. The effort required to complete each compaction cycle increases and may be excessive, especially when repeated several dozen times per working day.

3. Dual Controls. This is another variation which was available from several manufacturers as an option on some of their trucks. This arrangement allows the compactor to be operated from either side of the hopper by duplicate controls. But the danger introduced by such redundancy is obvious, and the latest ANSI standard, Z 245.1-1984, now prohibits dual controls because of the potential for damage and injury which may result whenever two operators fail to coordinate their actions.

Field observations and discussions with experienced operators revealed that despite the fact that both salvaging and jockeying are dangerous and unauthorized, both manuevers are done quite commonly. Salvaging refers to the retrieval of apparently valuable objects from the hopper as the packer- sweeper blade is descending. Jockeying is used to help dispose of materials which cannot be accommodated by the first pass of the packer-sweeper blade. Each of these techniques is made possible not only by the absence of a safety gate, but also by the location, orientation and operational sequence of the two control levers.

General Considerations for Control Lever Design

Positioning these levers further from the hopper is not feasible since this would create vehicle clearance problems. The levers should not extend beyond the outer boundary of the truck. If they did, this would directly increase the chances of their being damaged whenever the truck has to manuever in close quarters.

Another possible approach involves the use of locking pins, or an equivalent positive action mechanism. Now the levers could only activate the packer-sweeper blade when their pins were inserted into corresponding holes found on the body of the truck. With such an arrangement, there is only one pair of operating positions for the outer lever which controls packing motions, and one pair for the inner lever which controls sweeping motions of the blade. Moving the levers to any other position would not activate the mechanism. Jockeying would be discouraged, especially if the two set positions were located sufficiently far apart. Such an approach would also minimize chances for an inadvertent or undesired activation, or the slipping of a worn lever.

Human Factors Considerations

A full human factors engineering investigation should be carried out by the design team. The objective here is to determine correct dimensions, positions and operating techniques to use for the control lever mechanism. Since this arrangement is fixed, these factors must be based on the size and reach capabilities of a so-called "average" man. Such anthropometric data will be found in any standard text such as those listed in the reference section (6, 16).

The height of such controls usually corresponds with the mid-chest height of the 50th percentile or average sized worker. This is approximately 48 inches off the ground. But in any situation where one size must fit all, certain extreme sized operators (very tall or very short) may experience problems. Because they may have to stoop or reach excessively each time they activate the controls, both the speed and accuracy of their ouput may suffer. But such a result will arise whenever an "average" design approach is followed (11).

A far better design technique is to provide some built-in flexibility in workplace layout. For example, consider the front seat arrangement found in today's automobiles. Here a large amount of flexibility is provided in the design itself in order to accommodate a very large variety of body sizes (12). Unfortunately in our example, it is not practical to provide such flexibility for locating the compaction mechanism controls. Providing such flexibility appears to be quite expensive, so unless some new design concept is developed, we will be forced to accept the so-called average configuration already described.

A basic human factors analysis also shows that the current lever configuration is unsatisfactory with respect to the degree of safety it provides to the operator. He does have a full view of the hopper and its contents as the packer-sweeper blade loads the refuse into the body of the truck. This can prove helpful as it is sometimes necessary to halt the compaction cycle if a potentially dangerous object is spotted.

But this sole advantage is more than offset by a number of design defects. The two levers are virtually identical in length, size, color, position, and method of activation. They also have the exact same type of handle. Thus an inexperienced or inattentive operator could easily get them confused. Fortunately the consequences of such a mix-up are generally not critical

since there is usually enough time for the error to be realized and corrected. But why should a large potential for error be built-in here in the first place, when it is so easy to reduce by clearly distinguishing one lever from the other?

Another fundamental question which must be addressed is: are two control levers really necessary, or can the entire cycle by handled using a single lever? This arrangement is actually followed on some models of other manufacturers` collection trucks. But again from the human factors point of view, using only one lever to control the approximately 270 degrees of packer-sweeper blade motion may create problems. The high input-output relationship may make the control too sensitive. Overriding the desired position and backing up may occur all too frequently. These are basically inefficient processes which waste both time and effort.

However there are other weaknesses in the original lever design which can directly contribute to accidents involving the operators of such refuse collection trucks.

The planar orientation of the levers encourages the operator to stand parallel to the side of the truck and its axis of loading. In such a position, he is able to reach two feet or more into the hopper with his left hand while his right hand operates one of the control levers. This is precisely the stance assumed by our injured operator as he attempted to dislodge a piece of wood which had jammed the compactor mechanism.

If the control levers were reduced in length, they could be oriented perpendicular to the side of the truck body without creating any clearance problems. Some newer models of collection trucks made by the same manufacturer feature such significant design changes in their control levers. Compare Figures 7 and 8 (the newer design) with Figures 1 and 2 (the older design). These latter two photographs were taken of the truck actually involved in this accident. Note the following four major design improvements which have been made.

1. The overall length of the levers has been reduced from 21" to 6.5". This reduction changes both the magnitude and nature of the force which an operator can apply. A smaller and more precise input is the result.

2. The height of the levers above ground level has been increased from 48 inches to 66 inches. Again, this further reduces the amount of force which can be applied. It is also less convenient to activate a lever at eye height than at mid-chest height, but it has the advantage

Figure 7

Controls on New Refuse Collection Truck

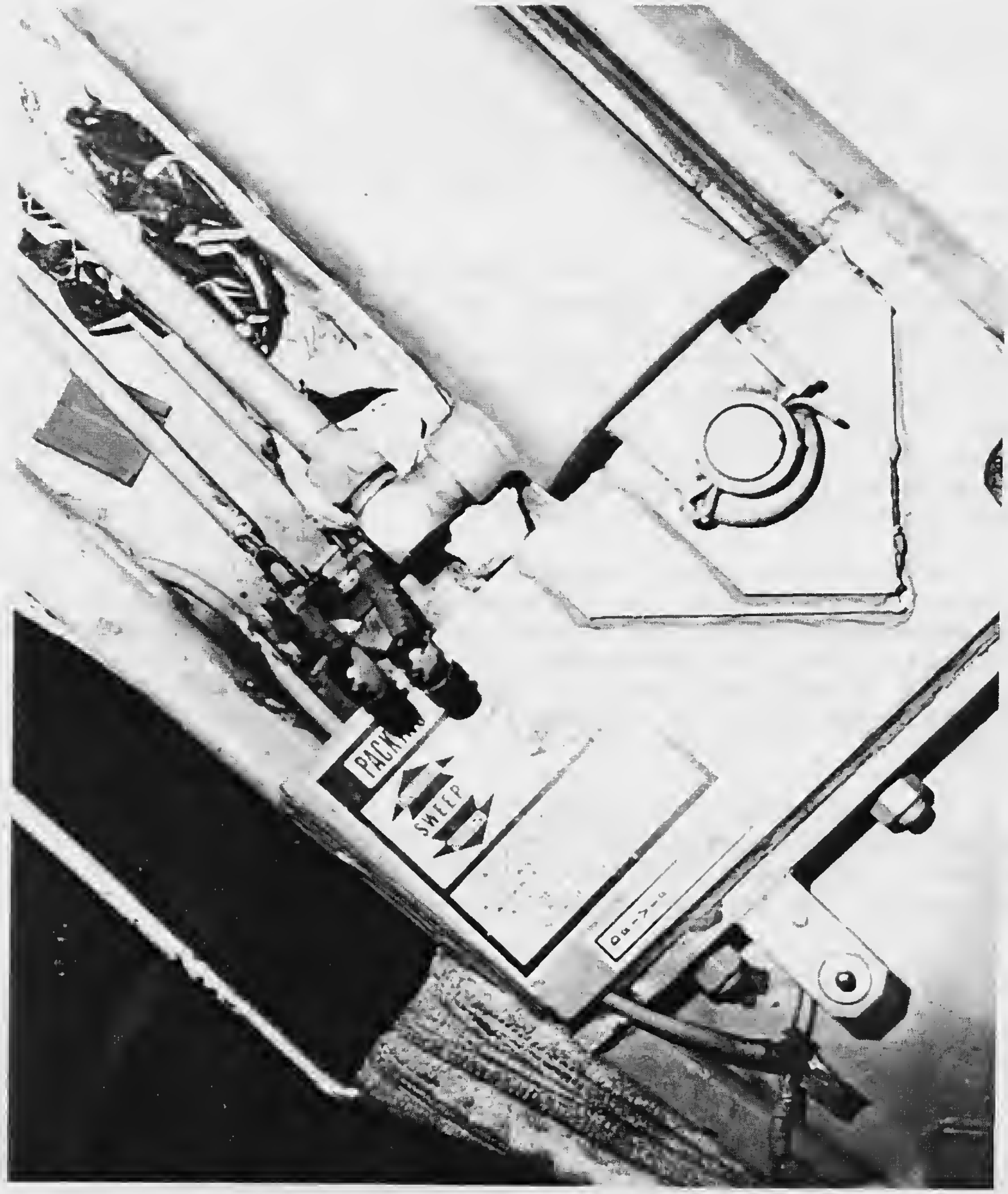

Figure 8

Close up of New Controls With Instructions

of encouraging the operator to assume a safer work stance.

3. The wrap-around grips have been replaced by ball shaped handles. The new handles allow the operator to use a power grip (See Figure 9) where the thumb is opposed to the fingers. The old handles required the thumb to be held parallel to the axis of the hand. The new grip is less fatiguing, and therefore represents a more efficient way to activate the blade. Biomechanical improvements such as this are significant whenever a control task must be repeated many times each working day. Physical fatigue is cumulative, and it well known that a tired operator is more likely to be involved in an accident. He may opt to ignore certain job details and thus increase the hazard exposure level he is willing to tolerate (14).

4. The plane of lever movement has been rotated 90 degrees. Such an arrangement now encourages the operator to stand perpendicular to the axis of loading, essentially preventing him from reaching into the hopper with one hand while operating a control lever with the other. Furthermore, if we locate the levers somewhat higher on the side of the truck, this makes it virtually impossible for all but extremely tall operators to now reach any portion of the hopper.

This new work stance does have one slight disadvantage. That portion of the hopper closest to the operator now cannot be viewed directly. However this limitation can be overcome if operators are trained to visually check this part of the danger zone for blockages or dangerous objects before initiating the compaction cycle.

On most new collection trucks, the final arrangement chosen for the compactor controls represents a compromise between two basic operator requirements. In essence they must be set up in such a way to meet the need to:

1. observe the entire hopper, and
2. make it awkward or inconvenient to reach into the hopper itself.

Since no single arrangement presently achieves both of these goals, designers must be satisfied with providing the best trade-off attainable (15).

Retaining good movement compatibility between control lever inputs and packer-sweeper blade outputs is

Figure 9

Wrap-around Grasp vs. Power Grip

essential. This relationship is not affected by the 90 degree planar rotation of the control levers. That is, a downward lever motion still results in a downward (or inward) response from the blade. The ratio of output movement to control lever input does increase somewhat with the new lever design. But tests have shown that this increase is not large enough to significantly change the operator's ability to do his job.

It appears that at some point in time, the manufacturer became aware of the deficiencies associated with the original control lever arrangement and proceded to design an improved version for a new line of trucks. Such a development is not all that uncommon. Most firms rely on field data from existing products to upgrade future models. These data include accident analyses which may point out product defects; they thus help to improve the safety features of new designs. Aside from the engineering effort involved in this particular change, there are no significant cost differences between the older control configuration and the new. But even this amount is insignificant when compared to the overall costs of designing and manufacturing a line of such vehicles.

The control lever arrangement on the newer refuse collection truck incorporates no new technology, so there is no reason why it could not have been implemented when the older line of trucks was originally produced. On the other hand, it does represent the result of a new form of analysis. This involves applying human factors engineering to the study of a true man-machine system - the operator and his truck. Such an analysis was clearly lacking in the original design.

The comprehensive design of any substantial man-machine control system involves many diverse parameters. Each of these must be taken into account, and wherever possible quantified, in order to optimize the operator's role. Without going into excessive detail, the major factors pertaining to proper lever design are listed below along with a brief description of important points to be considered in their selection (5).

1. Type of operation - either continuous adjustment or discrete motion may be indicated

2. Lever length - is particularly important where large forces must be exerted or large resistances overcome

3. Coding - an identification system must be used where more than one lever is involved for controlling

different functions. Color, shape, or head size are preferred cues in our example. Other possibilities include labels, orientation and method of operation. (Note Figure 7 which shows that the only cue used in this example was labeling.)

4. Control-display ratio - the ratio of lever movement to mechanism response. This factor establishes control movement sensitivity

5. Lever height - relative to the operator's working position, as well as spatial or planar orientation. These two factors directly determine how much torque or moment need be applied

6. Spacing provided - between adjacent levers, and clearances with other surfaces.

7. Form of resistance to movement offered - this may be either first order (spring resistance), second order (viscous damping), or third order (inertia). Naturally, the magnitude, duration and pattern of the resistance provided also plays a role.

8. Presence (or absence) of a neutral position - and the extent of any deadspace provided

9. For a discrete setting device - the arcs of motion required to both activate the mechanism and terminate its movement. These must be appropriate for the job involved, (neither too large not too small) 10. The presence of positive stops or passive display references.

It is quite unlikely that manufacturers lacking an experienced human factors engineering group would even consider any more than one or two of these ten basic factors leaving all of the others to either previous experience or to chance. Only if the application is relatively simple, or the company is lucky, is it possible to avoid problems arising as a direct result of human factors defects.

What About Warnings?

Designs should always alert equipment operators to the presence of serious hazards through the use of warnings. In addition to numerous warnings placed throughout the operation and maintenance manual, what are deemed to be the most important warnings were affixed to the body of the truck itself. These read:

1. Caution - stand clear of gate while unloading

2. Before starting, be sure that everyone is in the clear

3. Caution - stand clear while panel is in motion

4. Caution - stop engine before entering

But all such labels are of limited value in normal work situations. They are static displays which tend to lose their effectiveness quickly since workers see them all the time. They may have some initial effect on newer workers but tend to be largely ignored by more experienced ones. They are therefore only useful as back-up, but should never be depended upon as a primary means to prevent accidents. Proper equipment design, combined with thorough operator training should constitute the first line of defense in assuring occupational safety. This thinking is consistent with product liability law which states, that whenever there is a reasonable physical way to provide protection for the operator, then warnings alone are not an acceptable substitute.

Summary and Conclusions

It is generally agreed that refuse collectors are involved in a potentially hazardous line of work. The National Safety Council acknowledges that these workers sustain a significant number of work-related injuries every year. A good percentage of these injuries is connected with the collection truck's compaction mechanism. The partial or total loss of fingers, hands and arms are often the result of such accidents (9).

Comprehensive accident statistics are lacking, but larger cities with populations of 100,000 or more have submitted data covering 16.5 million man-hours of exposure during refuse collection. The accident frequency rate was 60.8 and the severity rate was 2,012 (10). These commonly used safety measures are defined as follows:

$$\text{frequency} = \frac{\text{number of disabling injuries X 1,000,000}}{\text{employee hours of exposure}}$$

$$\text{severity} = \frac{\text{total number of days charged X 1,000,000}}{\text{employee hours of exposure}}$$

Both the results for frequency and severity are exceptionally high with the frequency rate being approximately nine times that of the average industrial worker. Also, the high severity rate reflects the very

serious consequences of many such mishaps, i.e., permanent partial or total disabilities, or even fatalities.

As a general rule, equipment manufacturers should consider not only the correct or intended uses of their products, but also the more common ways in which they may be misused or abused. They should then apply this knowledge in formulating their designs to minimize the opportunities for any such unauthorized actions. There are many design techniques which can help accomplish this goal, some of which involve human factors engineering.

The N.S.C. Data Sheet previously cited notes that one of the more common types of refuse collection accident occurs when the operator of a truck compaction mechanism injures his left hand or arm by inserting it into the hopper while operating the control levers. This action may be done either consciously or inadvertently. Truck manufacturers must therefore take steps to minimize such opportunities and the accidents which may ensue. They could accomplish this by standardizing the use of effective barrier or point of operation guards. But we have seen that practical considerations often prevent this from happening. Hence they must also consider other possibilities such as revising the arrangement of the mechanism's control levers. This case study has shown how human factors engineering techniques can be applied in order to create arrangements which discourage operators from attempting inherently dangerous manuevers during the compaction cycle such as salvaging or jockeying.

Critics complain that safety engineers are paranoids who often interfere with designers to create products which do not function effectively. Contrary to these critics, it is seldom possible to make a product which is "too safe". Practical experience teaches the opposite is far more often the case.

Like any other design factor, safety must be considered on a direct costs-benefits comparison. Unfortunately in the past, the cost factors, which are relatively easy to determine, have been over-emphasized. The benefits to be realized from accident prevention are considerable, but they are usually far more difficult to quantify than the costs involved. There are direct benefits gained from fewer lost time accidents, but there are also many other indirect advantages to consider such as: improved workforce morale, increased productivity, reduced turnover, less time lost in accident investigation, or time needed to plan and implement procedural changes. All of these benefits of course are

in addition to a reduction in the number of operators hurt. If fully evaluated, the total effect of such benefits will often outweigh the costs involved (13).

Such a comprehensive analysis is needed to make inclusion of safety into basic design more feasible. One of the tools which can aid in such analyses is human factors engineering. The case discussed here explains this specialty by illustrating some of the advantages which it can provide. Hopefully its use will continue to increase as more and more engineers learn to appreciate what it can do for them, particularly with respect to achieving truly safe designs.

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